From sewage water treatment to wastewater reuse. One century of Paris sewage farms history

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Abstract The irrigation fields of Paris have been used for 100 years. Their soils mainly contain heavy metals in the topmost layer. Metals come from raw sewage as well as from digested sludge of biological treatment plants which have been diluted for years in raw water. Vegetables that are cultivated in the irrigation fields concentrate metals but their average contents, however, are lower than the recommended limit values. Some vegetables concentrate more specifically one type of metal. Corn seeds accumulate less metal than green vegetables. The SIAAP keeps operating irrigation fields by delivering clariflocculated water with a low metal content from the new Seine Centre plant, with the purpose of keeping some 2,000 ha of green zone in an otherwise heavily constructed area and to prevent a metal release from the soil should irrigation be interrupted. Maintaining irrigation fields also relieves the biological treatment plant and then contributes to preserve the quality of the Seine river, especially in summer.
Keywords Irrigation fields; irrigation; heavy metals

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Introduction

After the construction of water supply works and sewers in Paris, which was initiated in 1856, the river Seine became heavily polluted downstream from the sewers and solutions had to be found. Experimental sewage treatment processes were tested in the years 1868 and 1869 at Clichy and led to the first achievements – namely irrigation fields at Gennevilliers in 1872, which only could handle a minor part of the daily wastewater output. A global wastewater treatment project that was designed in 1875 was only implemented in 1895, due to "the direct to drain" law which gave birth to municipal sanitation, including technical, legal and financial aspects. The law resulted in the facilities of the present sewerage system (Benoist, 1973).

At the beginning of the twentieth century, when the irrigation fields reached their maximum extent, there were 4 sewage irrigation areas around Paris: the initial Gennevilliers fields, extending over 900 ha, and the Achères fields comprising a set of three distinct areas, namely the 1,400 ha Achères plain, the 2,010 ha Pierrelaye area and the 950 ha Triel area. The three areas of the Achères fields were supplied with raw sewage from the Colombes pumping plant through a 22 km long main outfall sewer. The whole irrigation fields, which received about 160 million cubic metres a year, only treated a part of the daily sewage from the city due to insufficient area dedicated to the irrigation. The untreated sewage (about 250 million cubic metres per year) was discharged to the Seine river and contaminated it. The situation lasted up to the activated sludge biological purification project that was designed in 1935 but was gradually implemented and periodically modified. The first unit of the Achères treatment plant was commissioned in 1940; the last one, namely the Seine Centre plant, came on stream at Colombes in 1998 (*Notes à l'appui du compte* 1980, 1979 and 1968).

Since 1998, the brand new Seine-Centre treatment plant in Colombes supplies all three irrigation zones with a half-clarified sewage treated in flocculation tanks, which has the properties of a very good primary settled water. In summer time, when the fields need more

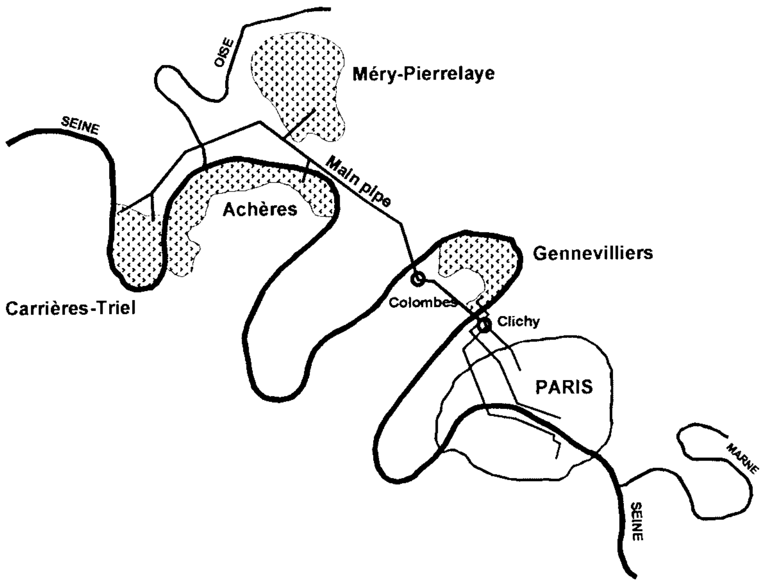

Figure 1 Irrigation fields of Paris in 1900

Table 1 Irrigation fields area during one century

Year	Total irrigated area ha	Yearly flow of water $10.^6$ m^3/an
1904	5,100	200
1950	5,000	100
1980	2,010	40

water for the crops, purified water is added to the clarified water so that the irrigation water flow is maximal in three months, namely July, August and September whereas the clarified flow being pumped through the fields is far lower during the rest of the year.

Though irrigation took place through water flow in surface furrows rather than by sprinkling, the health hazards were acknowledged as soon as the fields were equipped for irrigation. Polemics rose about their alleged dangerous effects. Bacteriology, a new science in 1880, did and still does not favour the technology of irrigation for fear of scattering noxious bacteria, pathogenic germs, protozoan parasites, helminth eggs… The new, long unnoticed risk involved by the concentration of metals in soil and vegetables recently raised further concern about the irrigation fields.

Laws about the irrigation fields were issued in order to control the acknowledged town sewage irrigation-related hazards:

- The regulations established a maximum rate of 40,000 m^3/ha/year sewage on vegetable fields and 60,000 m^3/ha/year for intensive irrigation on grassland.
- The health and sanitary rules forbid irrigation on fields yielding vegetables that are eaten raw.
- More recently, the Sanitary Counsel of France (CSHP) recommended limit values of metal contents in soils and vegetables (Boisset and Juste, 1999).
- The recent water law issued in 1992 (Loi sur l'eau, 1992) submits both effluent application and re-use of treated sewage for irrigation purpose to a prior authorisation by the Sanitary authority.

The Pierrelaye fields

In the fields of the Achères region, the Pierrelaye zone contains the greatest vegetable cropping area and therefore has to face the sharpest sanitary problems.They are located at a 45 m elevation above the Seine. Unlike the fields of Achères plains the soil of Pierrelaye is made of sedimentary formations that are frequently found on the top of Parisian hills, that is to say in tertiary sands and sediments of plateaux. The various types of permeable soils outcrop at the surface of the plateau that is notched by two tiny valleys: the Vaux brook and the Liesse brook, both of which are turned into natural drains collecting the purified percolated sewage water.

Three main water works were constructed: a pumping plant built in 1900 to convey the sewage up to the top of the plateau and to the distant fields; a 92 km long raw sewage distribution network with 2,160 distribution outlets fitted with manually operated valves; a 40 km long drainage system with open air and underground pipes to collect infiltrated sewage purified by percolation through the soil.

There were originally two types of field management with quite different purification abilities. Municipal lands, which belong to the city of Paris, in which a constant, great sewage flow is to be handled: the extensively irrigated fields where corn or any industrial crop is grown (1/3 of the Pierrelaye irrigated area). The Haute Borne farm, which was municipally owned was long a model farm in France (first silage experimentation with bacteria, mechanical ploughing, milk production, veterinarian measures against tuberculosis). In privately owned fields (2/3 of the Pierrelaye irrigated area), the farmers may irrigate as they want it, according to their vegetable productions. They mainly use sewage water when vegetables need water. The irrigation area in the Pierrelaye fields remained constant through the twentieth century and started to decrease after 1980 as an effect of road construction and urban development.

Heavy metal contents in the soils of irrigation fields

Results of Cd, Hg, As, Pb, Cu, Zn content measurements (Boisset *et al*. 1999), as expressed in mg/kg of dry soil in irrigated and non-irrigated soils at three levels of soil depths are summarised in table No. 2 which illustrates obvious facts.

1. The highest metal concentrations in irrigated soils can be found in the surface layer (0–30 cm). Humic matter, which is also more concentrated in the surface layer of soil, binds the metals differently according to the type of metals, following the decreasing order : Zn, Pb, Cu, As, Hg, Cd. The first three metals have high concentrations, over 130 mg/kg of dry soil in surface soil, and the other metals exhibit concentrations less than 8.5mg/kg of dry soil in surface soil.
2. Concentration rate in irrigation soil as compared to control soils follows the decreasing order Pb, Cu, Zn, Hg, Cd, As. Arsenic displays no accumulation in an irrigation soil as compared to a control soil.

Table 2 Heavy metal contents of irrigation fields and control soils

Elements Mg/kg dry	Raw water irrigation Soil depth (cm)			Control Soil depth (cm)		
	0–30	30–60	60–90	0–30	30–60	60–90
As	8.42	10.4	6.83	9.86	7.93	9.61
Cd	2.17	0.92	<0.8	<0.8	<0.8	< 0.8
Hg	2.55	2.9	0.83	0.49	0.39	0.16
Pb	273.64	120.9	40.30	24.05	15.50	14.89
Cu	138.03	70.2	25.15	15.00	12.06	12.33
Zn	431.55	242.5	88.03	56.11	52.58	56.79

3. Metal concentrations in soils that are irrigated with raw sewage decrease with depth. The humic matter binds metals at various rates according to metal types. The heavy metal concentrations in control soils do not significantly decrease as compared to irrigated soils.
4. The lead in control soils exhibits an unusual pattern of depth distribution. It behaves like a metal coming from the surface. This is probably due to air pollutants.

These concentration in irrigated soils are compared to the French standard NF U 44-041 which sets the maximum limit of heavy metal contents in soils (Nadeau, 1996). It is noteworthy that the concentrations of metals at the surface of irrigation fields (Table 2) exceed the recommended limits of metals in soils in all cases (Table 3). Thus, irrigation has to be stopped if an interruption of irrigation ha no subsequent detrimental effect.

The present situation is the result of one century of irrigation. From 1900, the year when irrigation was started in the three zones of Achères up to 1998, when the new Seine-Centre plant came on stream, the irrigation fields received raw sewage from the main pipes of Paris urban districts. Others influents were introduced into the main pipe, namely digested sludge from the Colombes treatment plant since 1935 up to 1992 and digested sludge from the two Achères treatment plants from 1940 to 1952, when a sludge treatment workshop was constructed in Achères. Thus, heavy metals from the soil are concentrated in the vegetable tissues, and are transmitted to man later on.

Two heavy metals, Zn and Cd, were chosen to compute the input in the soil in about 100 years. Zn is characteristic of Parisian sewage due to the house roofs being covered with zinc plates. Therefore, sewage contains a fairly constant concentration of Zn over the time. Cd, on the contrary is characteristic of an industrial activity. The Cd content in sewage increases during the century and decreases more recently due to treatment in fabrics (Timbard, 1973).

The following assumptions had to be made for evaluating the rate of heavy metal in soils : the fields receive raw sewage during 92 years; the average sewage flow rate was of 200M cu./year for the first 50 years (Cd being almost absent and Zn concentration being 0.4 mg/l). In the next 42 years they received raw sewage at a lesser flow rate of 60M cu.m/year, with Cd = 5µg/l and Zn = 0.4 mg/l. Digested sludge from Colombes, once diluted in the raw sewage, was discharged to the fields for 57 years. Digested sludge from Achères plant I (treating 200M cu.m sewage/day) was applied in the field for 25 years and digested sludge from Achères II (treating 300 M cu.m/day) for 5 years.

The computed Cd and Zn inputs over the 3,700 ha of irrigation fields during the century are displayed in tables 4 and 5, as well as in the corresponding Figures 2 and 3.

Table 3 Limits values of heavy metal contents in soils

Metal mg/kg	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Limit values of metals in soils (mg/kg)	2	150	100	1	50	100	300

Table 4 Cd and Zn supply in soils during one century

Input	Weight in tons during application		Number of years of application
	Cd	Zn	
Raw sewage	12	4080	92
Digested sludge from Colombes	2.4	273	57
Digested sludge from Achères I	10.4	1401	57
Digested sludge from Achères II	4.3	350	5
Total	30	6000	

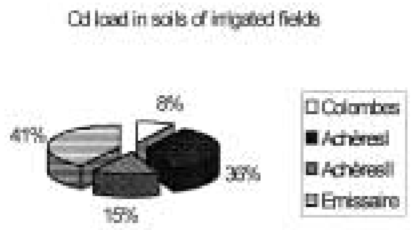

Figure 2

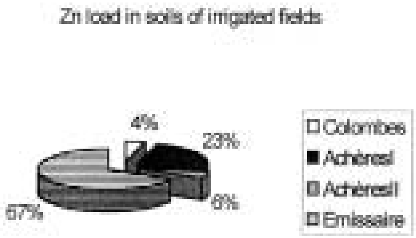

Figure 3

Table 5 Supply of Cd and Zn calculated in soils compared to measures

	Cd	Zn
Input (kg/ha)	8.1	1621
Input mg/kg dry soil(0–60 cm)	4	1224
Metal content as measured in soil mg/kg dry soil	0.8–40	100–820

The evaluations of Cd concentration in soils over 100 years agree with the values obtained by dosage of the soils (Table 5). The distribution of digested sludge in sewage accounts for almost 60% of the Cd content in the soil and almost 30% of Zn content in the soil. The digested sludge from Colombes has lesser effects than the sludge from Achères because it is derived from less industrial sewage and the yearly flow is lower in spite of a longer application.

Properties of sewage water applied to the fields

Sewage applied to the fields before and after the Seine-Centre treatment plant have the following characteristics (Table 6). Table 6 shows that the average sewage load distributed in the fields after putting the Seine Centre plant into service has lower BOD_5 and NH_4 values than before. Furthermore, it contains nitrates due to the injection of purified water into the clariflocculated water distributed in the fields (Rougemaille, 1996, 1997, 1998).

The results are expressed by two extreme values, namely the maximal and the minimal values as recorded in a one-year bacterial counting campaign. Faecal coliform and streptococcus contents in the sewage applied to the field before and after the Seine-Centre plant are displayed in Table 7. Bacteriological values in drain water after percolation are also presented. It is noteworthy that after 1998 (after the Seine-Centre plant commissioning) the

Table 6 Chemical parameters in raw sewage and clarifloculated sewage

Averages Values	MES mg/l	BOD_5 mg/l	COD mg/l	TKN mg/l	NNH_4 mg/l	NNO_3 mg/l	PPO_4 mg/l	Cd mg/l	Pb mg/l	Zn mg/l	Cu mg/l
Before 1998	177	162	277	25	20	0.10	3.2	0.005	0.050	0.400	0.900
After 1998	23.5	30	76	14.7	11.5	3.9	0.2	0.002	0.022	0.120	0.064

Table 7 Bacteriological parameters in raw sewage and clarifloculated sewage before and after 1998. Results for 100 ml of analysed water

	After "Seine centre"				Before "Seine centre"			
	Faecal coliforms		Faecal Streptococci		Faecal coliforms		Faecal Streptococci	
	maxi	mini	maxi	mini	maxi	mini	maxi	mini
Supplying to Pierrelaye irrigation fields	1.5×10^7	5×10^3	1.5×10^6	5×10^2	2×10^7	2.5×10^6	5.5×10^6	7.5×10^4
General drain outflow	1.5×10^4	1×10^2	3.5×10^3	5×10^1	5.5×10^4	2.5×10^3	1.5×10^4	1×10^2

bacterial count decreases in the sewage applied to the fields. The lowest values are very different before and after Seine-Centre due to the fact that a mixture of purified and flocculated sewage is applied to the fields after 1998 (Védry and Moncaut, 1997, 1998, 1999).

The water leaving the drain after percolation shows a lesser difference in bacterial counting between the two types of water before and after Seine Centre, what means that the soil dampens the difference in input water.

Heavy metal content in vegetables grown in irrigated soils

A campaign of metal content measurement in soils and vegetables was carried out in 1998 in irrigated fields in control soils and in vegetables grown on this two types of soils. Table 8 summarises arsenic, cadmium, mercury and lead contents in 5 main vegetables grown in the fields, as expressed in µg/kg moist vegetable.

The vegetables from irrigated soils display highly variable metal concentrations according to the types of vegetables. Celery concentrates large amounts of cadmium whereas leeks and lettuces mostly concentrate lead.

On average, and for each vegetable, it appears that the metal concentration thresholds are not exceeded. In the case of Pb, however, statistics showed that 7 samples of leeks out of 15 exceed the recommended value of metal contents, which is 300 µg/kg moist matter, and that one sample of lettuce out of 12 exceeds the recommended value, which is 500µg/kg moist matter in that case. There is no recommendation for arsenic. For safety reasons, however, these findings induced the authorities to forbid vegetable farming on irrigated fields in 1999.

All the corn seed samples, however, show a metal content which is much lower than the limit values (refer to Table 8) which is consequently in favour of corn culture on irrigated soils. Note that seeds are drier than vegetables, and that therefore on a dry basis they contain less metal than vegetables.

Conclusion

In the years around 1890 irrigation fields were the only way to treat sewage from large cities. That process could hardly compete with the biological processes, especially the successful activated sludge process. The capacities of water treatment plants of the Greater Paris now are sufficient to handle the whole amount of sewage, and the irrigation fields are no longer a compulsory tool to purify a part of the daily sewage. The possible health hazards (Gandois-Ruban, 1993; Roy and Couillard, 1997) constituted by vegetables grown on irrigated soils led to the end of the traditional cultivation of vegetables in the Pierrelaye fields. The local authorities, however, are eager to maintain healthy crops in an otherwise over-urbanised area. The existing infrastructure, which is inherited from a 100 year practice, may assist to keep on irrigating in a new way: irrigation with reused treated sewage water which reduces the heavy metals contamination of the soils through the cultivation of

Table 8 Heavy metal contents in vegetables of irrigated and control fields. **AS**: irrigated fields AS: control fields

µg/kg moist	**As**	As	**Cd**	Cd	**Hg**	Hg	**Pb**	Pb
Onions	**5.8**	8.7	**7.2**	5.6	**5.5**	1.8	**49.5**	10
Parsley	**13.2**	30.3	**4.4**	3.3	**6.1**	3.6	**81.9**	32.,6
Lettuce	**15.7**	6	**27.7**	34	**6.4**	4.0	**220**	30
Leeks	**17.,7**	16.3	**5.8**	7.6	**6.5**	2.6	**229**	25.6
Celery	**18.7**	4. 6	**70.3**	21	**8.9**	4.0	**25.2**	12.6
Corn	**37.7**	32.3	**13.4**	2.6	**3.9**	3.3	**32.1**	7.3
CSHP Limit value.			100		30		300/500	

corn seeds raising no sanitary objection as to their heavy metals content and bacteriological properties. The reuse of treated sewage, the daily flow of which reaches up to 300,000 m^3/day in summer, helps to reduce the residual pollution discharged to the river Seine thanks to the astonishing purification power of the soil.

New investigations are besides carried out on the irrigation fields to assess the evolution of soils loaded in heavy metals. In conclusion, sewage farms belong to the past, reuse of already purified sewage water seems the way of the future.

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